Space Exploration enabled by Onboard Computing and Decision-making

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slides & images: http://ai.jpl.nasa.gov/public/home/chien/spring-agu-2006.html

7 May 2004 ASE monitors Mt. Erebus

ASE images Erebus Night — 13:40 GMT

} +10 min

ASE initiates band extraction

} +28 min

ASE runs thermal classifier

} +29 min

THERMAL TRIGGERED

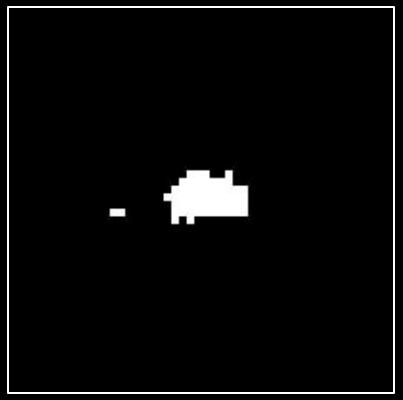
Planner selects reaction observation (Stromboli observation replaced)

} +20 min

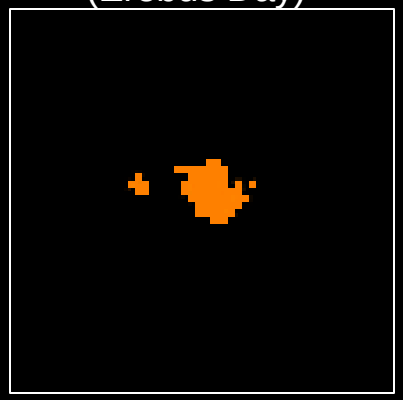
Thumbnail downlinked (S-band) — 15:58 GMT

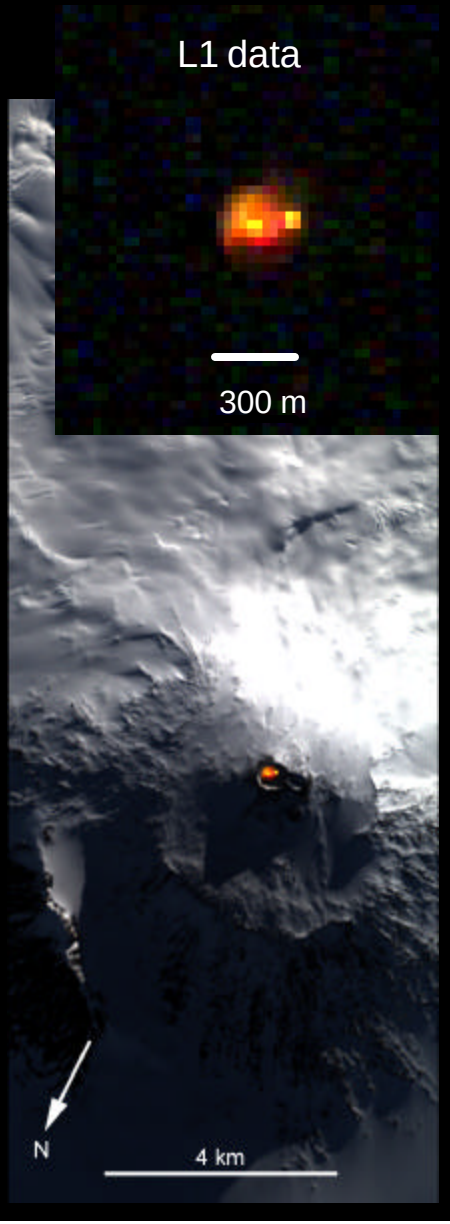
ASE images Erebus again — 20:10 GMT + 06:30

ASE Onboard Thermal Classifier Thumbnail (Erebus Night)

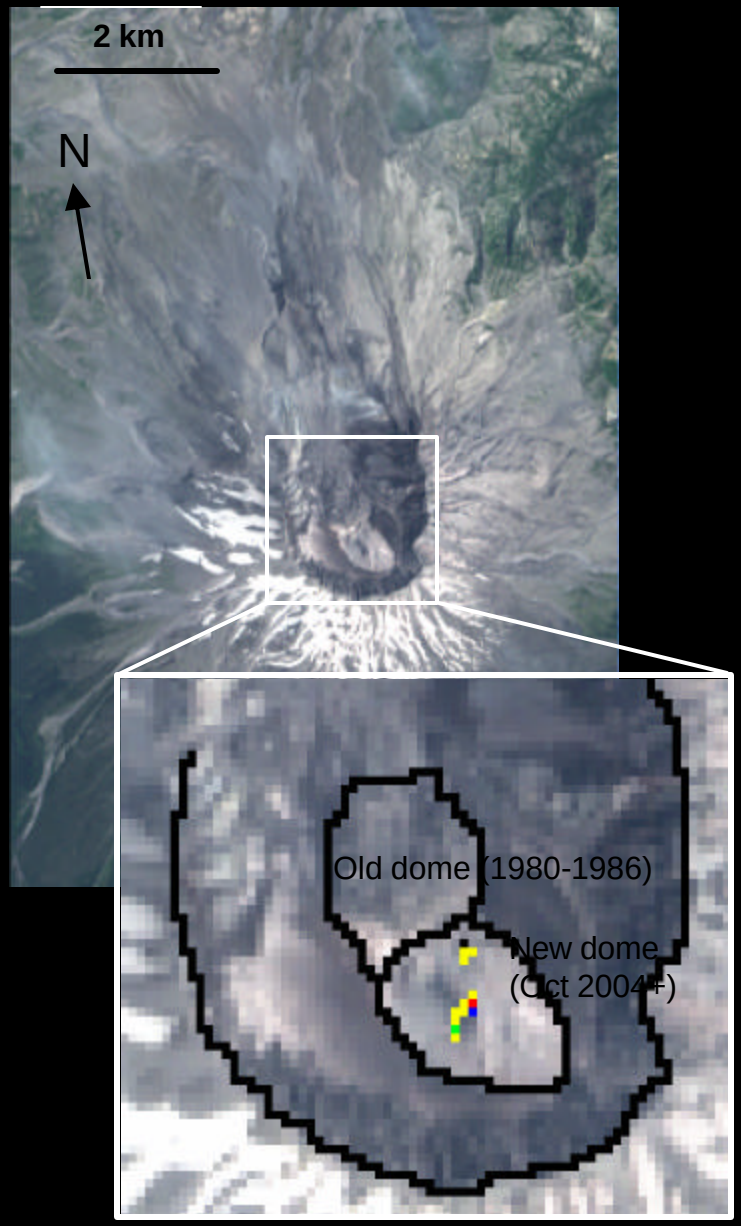


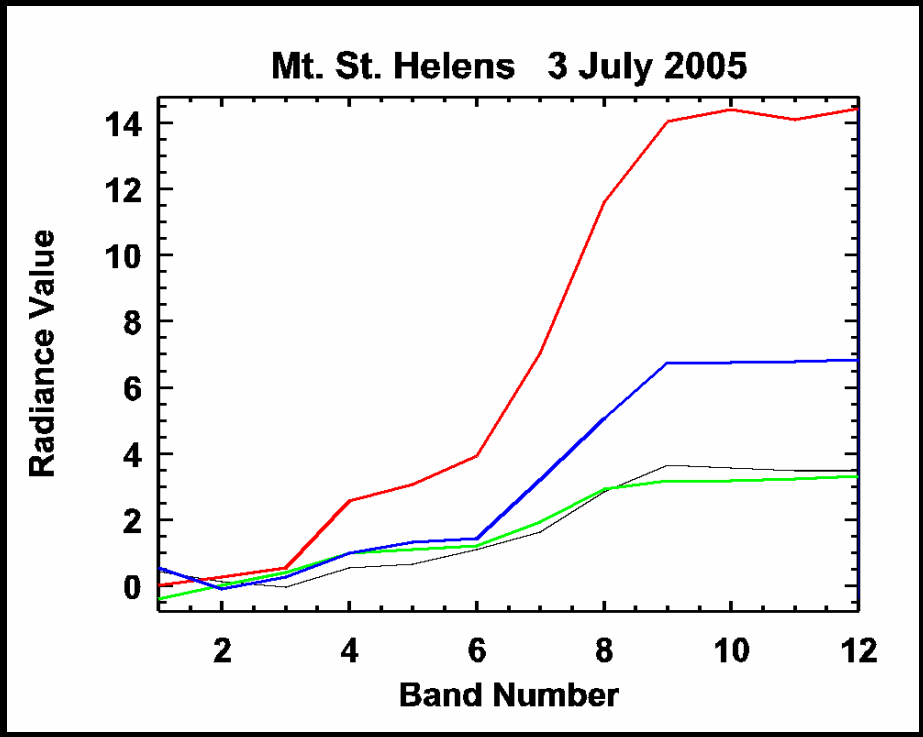
ASE Onboard Thermal Classifier (Erebus Day)





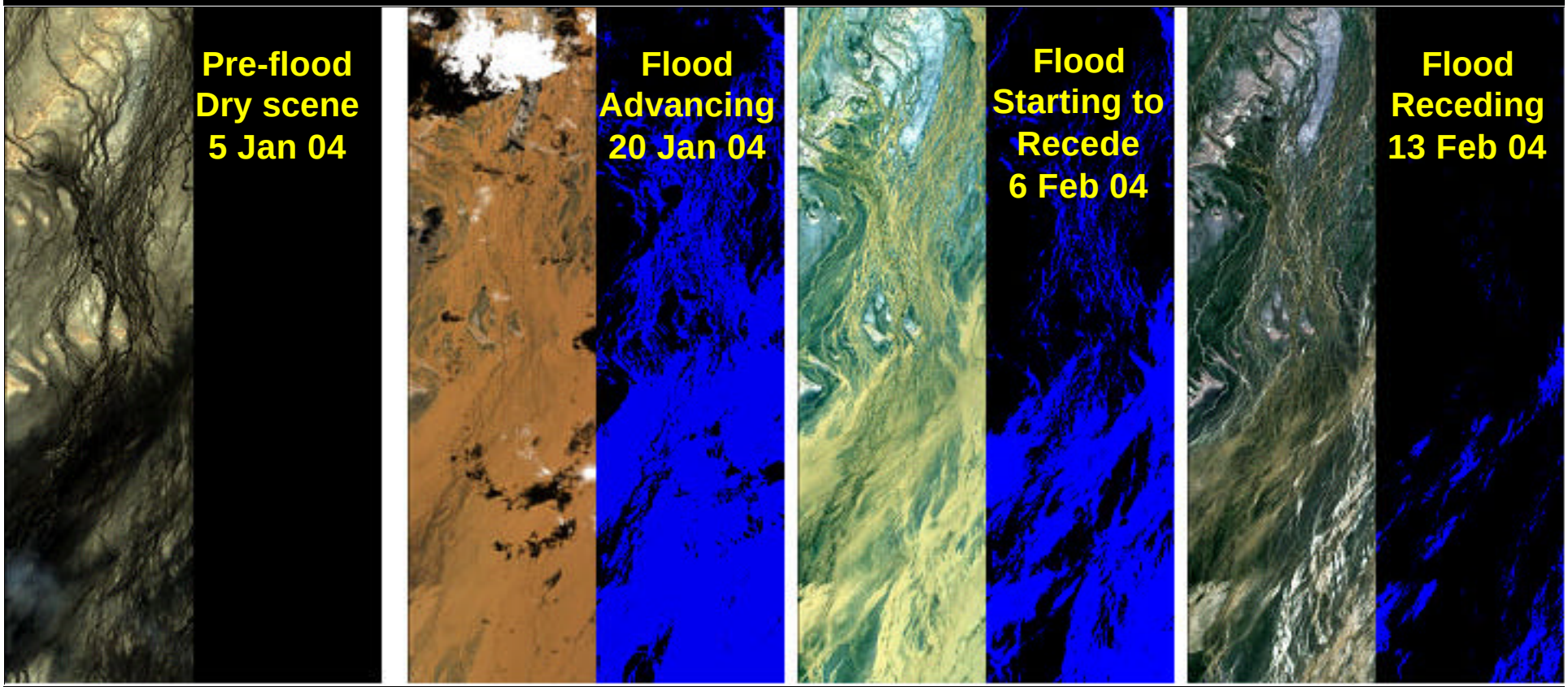
- **ASE enabled rapid notification of volcanic event**
- **ASE enabled rapid re-imaging of this event**
- **Autonomous response as normal operations!**
  - **Highest leverage for deep space missions**





Band	Wavelength, µm	Band	Wavelength, µm
1	0.630	7	2.022
2	1.245	8	2.103
3	1.266	9	2.254
4	1.599	10	2.264
5	1.659	11	2.274
6	1.780	12	2.285

Detection of a Rare Major Flood on Australia's Diamantina River using the ASE "Muddy" Floodwater Classifier



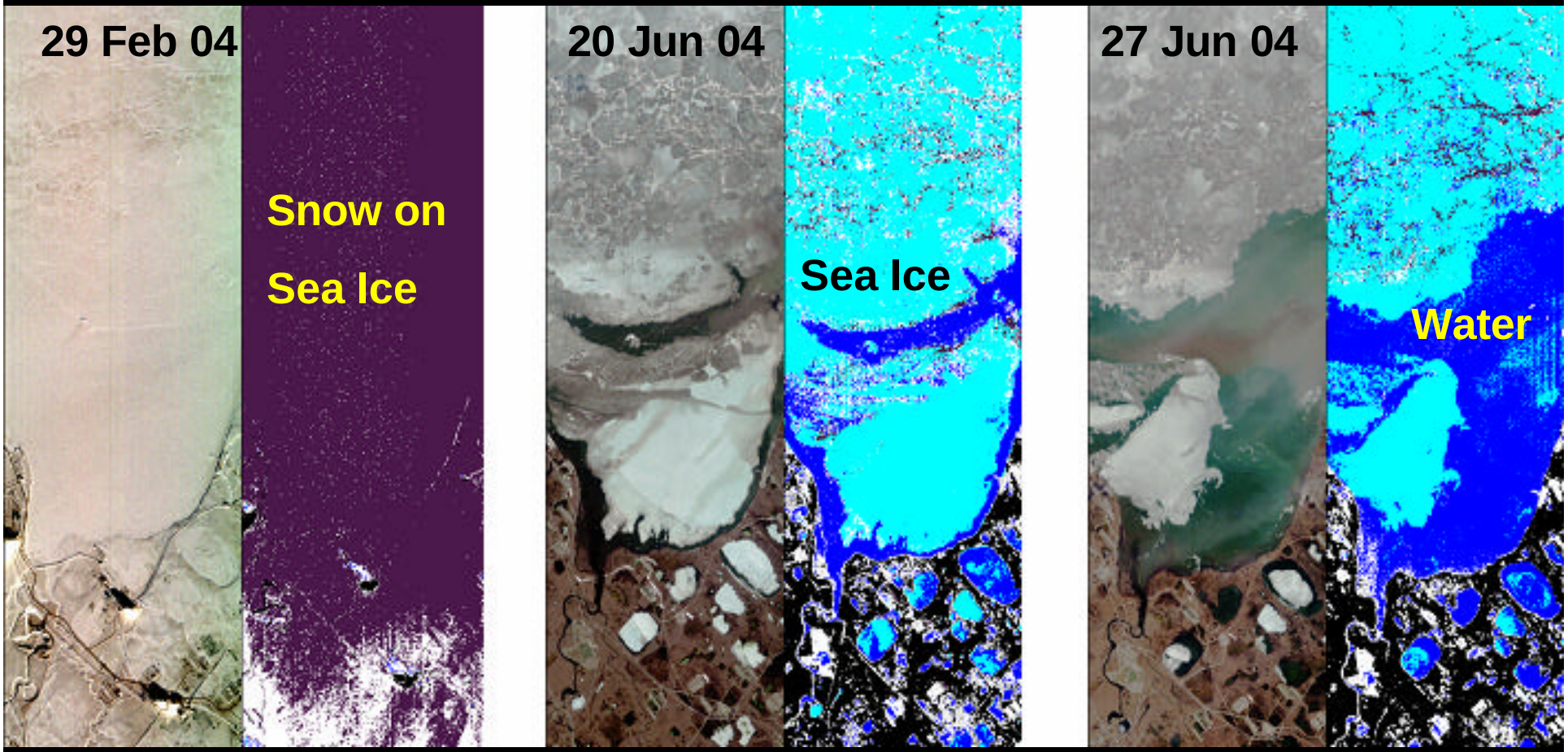
Cause of flooding: Monsoonal rain

Wavelengths used: 0.86 µm and 0.99 µm

V. Baker, F. Ip, & J. Dohm, University of Arizona

Cryosphere Classifier

Deadhorse (Prudhoe Bay), Alaska



Snow
Water
Ice
Land
Unclassified

Wavelengths used in classifier:
0.43, 0.56, 0.66, 0.86 and 1.65 µm

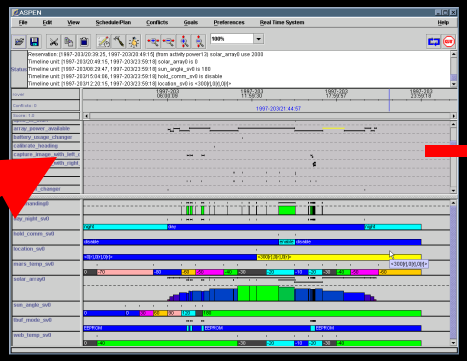
R. Greeley & T. Doggett
Arizona State University
Planetary Geology Group

ASE Current Status

- Current count > 5000+ autonomous data collects
  - 1st flights in Fall 2003
- **ASE Software so successful it is now in use as baseline operations for the remainder of the mission (Nov 2004-)**
  - **Enabled > 100x increase in science return**
    - **Measured as: # events captured / MB downlink**
  - **Enabled a reduction in net operations costs $3.6M/year → $1.6M/yr ; over $1M of reduction directly from ASE**
    - **Operations cost reduction critical in enabling extended mission Oct 2005 – Oct 2007**

Sensorweb

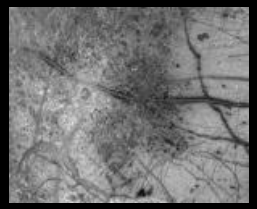
Re-tasking



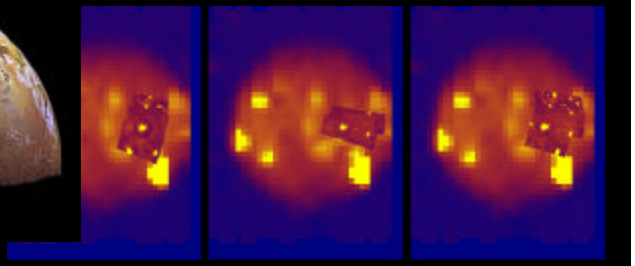
Earth Observer One

Triggers so far: Wildfires, Floods, Volcanoes (thermal, ash), Ice/Snow, in-situ sensors, modified by cloud cover

Future Missions



Tracking crustal motion
for Europa Orbiter



Io Volcanism

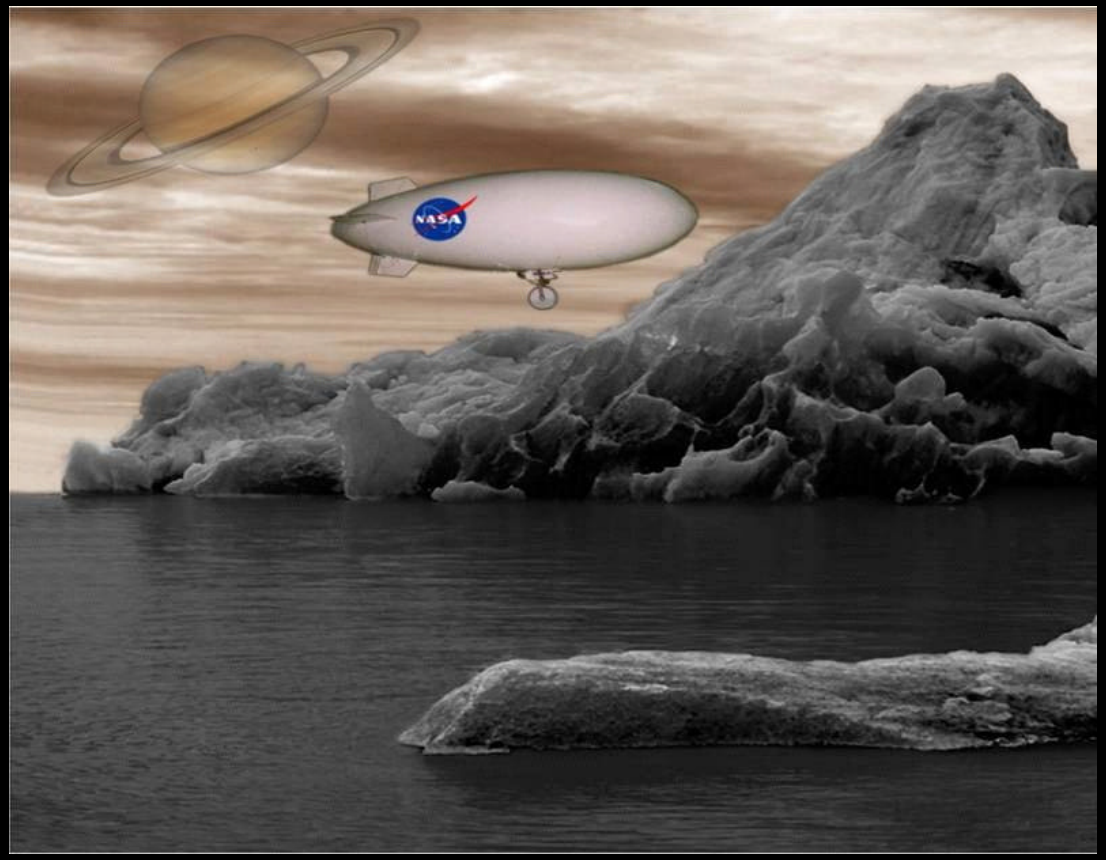
Europa Cryobot

Comets

Exploring Titan

Ralph Lorenz
Lunar and Planetary Laboratory
University of Arizona

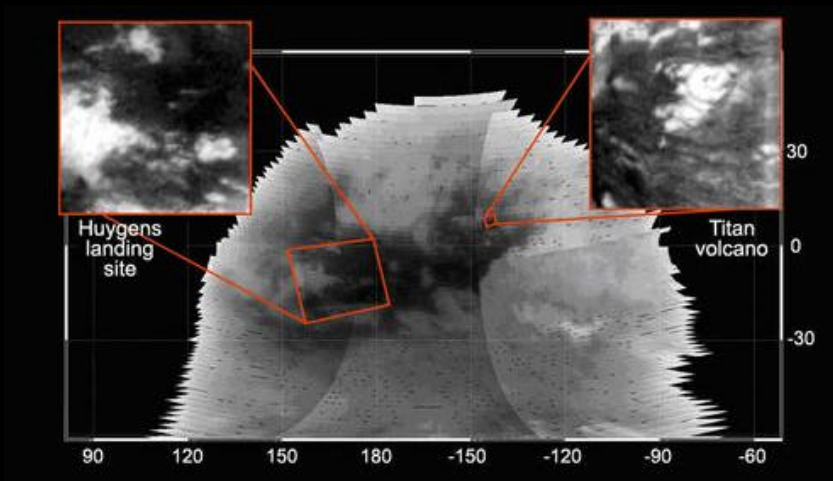
Exploring Titan

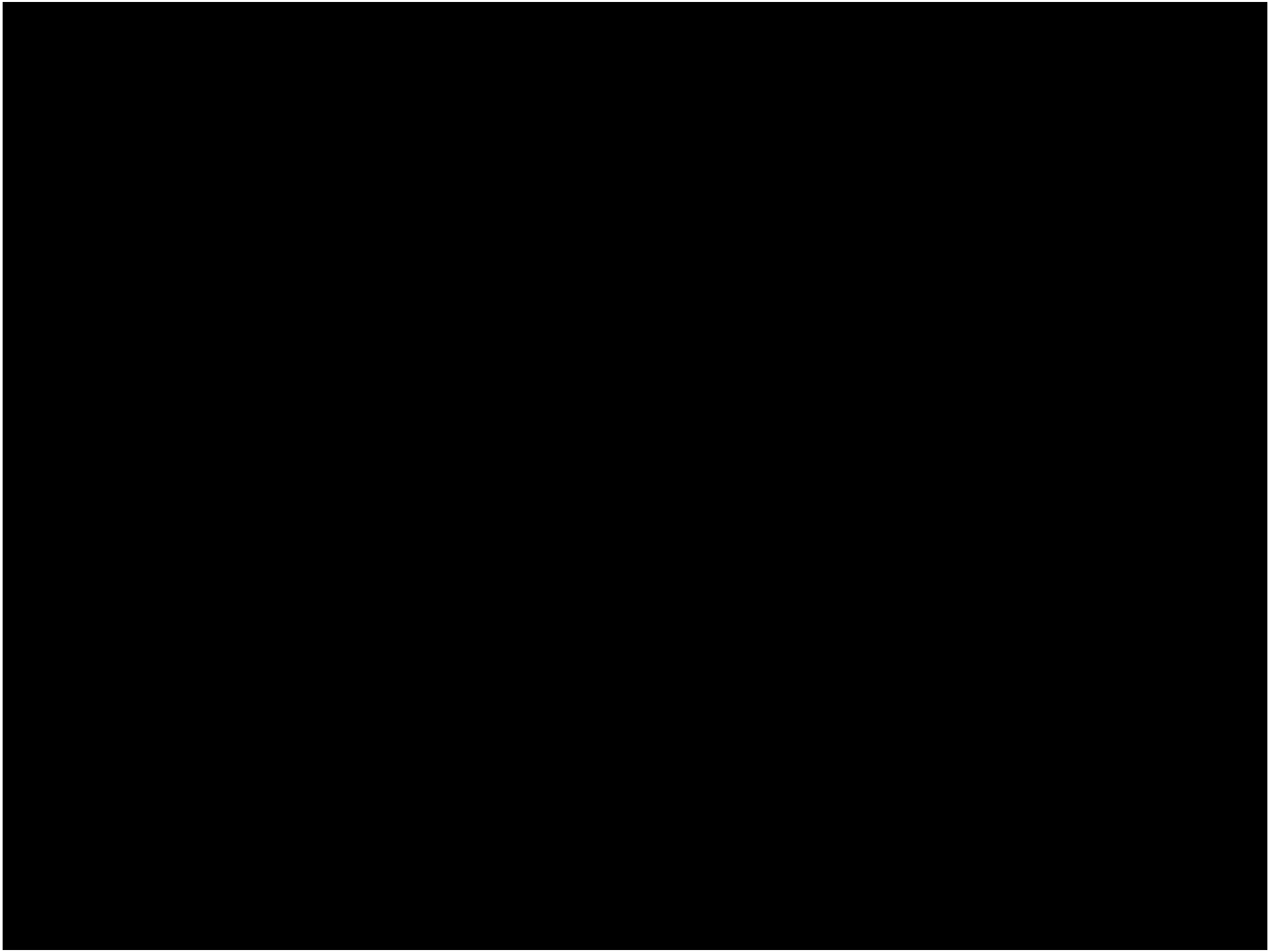


- Autonomy Drivers
  - Round trip light time make joysticking untenable
  - Distance and limited power makes downlink limited

Exploring Titan (cont'd)

- Autonomy could enable an aerobot to detect and image transient phenomena e.g.:
  - Methane Thunderstorms,
  - Methane Geysers, or a
  - Cryovolcano





Science Response

Image taken by Spacecraft

Science Response

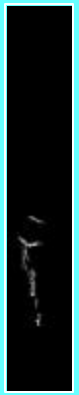
Image taken by Spacecraft

Onboard Science Analysis

Event Detection

No event Detected: Delete Image

Event Detected



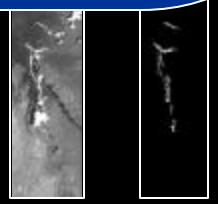
ASE uses state of the art Machine Learning to detect events in the presence of noise

Track a wide range of science events – floods, volcanoes, cryosphere, clouds,…

Key Insight: No need to replicate ground science analysis – just detect activity

Science Response

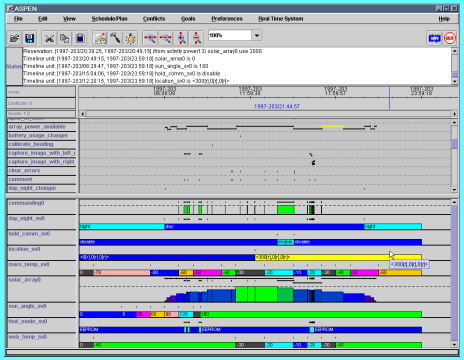
continuous planning - enables seamless long-duration operations and rapid replanning despite limited onboard CPU



Autonomous Planning

No feature Detected: Delete Image

Goal



Feature Detected

Downlink Image and Possibly Re-image Same Area

Goal

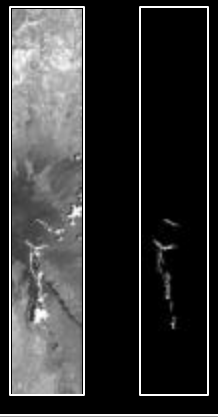
Retarget for New Observation Goals

Onboard planning enables rapid response to detected event

Science Response

Image taken by Spacecraft

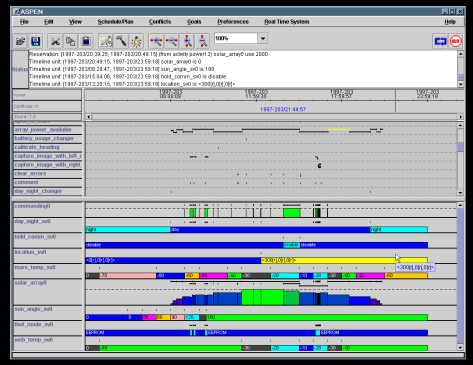
Land Feature Detection



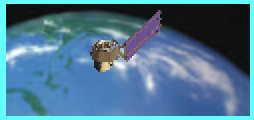
No feature Detected: Delete Image

Feature Detected

Downlink Image and Possibly Re-image Same Area



Retarget for New Observation Goals



New Science Images

Autonomous Execution

Event-driven execution of response image